

Edited by
Sunit Ghosh | Florian Falter | David J. Cook

Cardiopulmonary **Bypass**



CAMBRIDGE
Medicine

Cardiopulmonary Bypass

Cardiopulmonary Bypass

Edited by

Sunit Ghosh

Florian Falter

David J. Cook



CAMBRIDGE
UNIVERSITY PRESS

CAMBRIDGE UNIVERSITY PRESS
Cambridge, New York, Melbourne, Madrid, Cape Town, Singapore,
São Paulo, Delhi, Dubai, Tokyo

Cambridge University Press
The Edinburgh Building, Cambridge CB2 8RU, UK

Published in the United States of America by
Cambridge University Press, New York

www.cambridge.org
Information on this title: www.cambridge.org/9780521721998

© S. Ghosh, F. Falter and D. J. Cook 2009

This publication is in copyright. Subject to statutory exception
and to the provisions of relevant collective licensing agreements,
no reproduction of any part may take place without the written
permission of Cambridge University Press.

First published 2009

Printed in the United Kingdom at the University Press, Cambridge

*A catalog record for this publication is available from the
British Library*

ISBN 978-0-521-72199-8 Paperback

Additional resources for this publication at
www.cambridge.org/9780521721998

Cambridge University Press has no responsibility for the persistence or
accuracy of URLs for external or third-party Internet websites referred
to in this publication, and does not guarantee that any content on such
websites is, or will remain, accurate or appropriate.

Every effort has been made in preparing this publication to provide
accurate and up-to-date information which is in accord with accepted
standards and practice at the time of publication. Although case histories
are drawn from actual cases, every effort has been made to disguise the
identities of the individuals involved. Nevertheless, the authors, editors
and publishers can make no warranties that the information contained
herein is totally free from error, not least because clinical standards are
constantly changing through research and regulation. The authors,
editors and publishers therefore disclaim all liability for direct or
consequential damages resulting from the use of material contained in
this publication. Readers are strongly advised to pay careful attention to
information provided by the manufacturer of any drugs or equipment
that they plan to use.

Contents

List of contributors vii

Preface ix

-
1. **Equipment and monitoring** 1
Victoria Chilton and Andrew Klein
 2. **Circuit setup and safety checks** 23
Simon Colah and Steve Gray
 3. **Priming solutions for cardiopulmonary bypass circuits** 36
George Hallward and Roger Hall
 4. **Anticoagulation, coagulopathies, blood transfusion and conservation** 41
Liza Enriquez and Linda Shore-Lesserson
 5. **Conduct of cardiopulmonary bypass** 54
Betsy Evans, Helen Dunningham and John Wallwork
 6. **Metabolic management during cardiopulmonary bypass** 70
Kevin Collins and G. Burkhard Mackensen
 7. **Myocardial protection and cardioplegia** 80
Constantine Athanasuleas and Gerald D. Buckberg
 8. **Weaning from cardiopulmonary bypass** 92
James Keogh, Susanna Price and Brian Keogh
 9. **Mechanical circulatory support** 106
Kirsty Dempster and Steven Tsui
 10. **Deep hypothermic circulatory arrest** 125
Joe Arrowsmith and Charles W. Hogue
 11. **Organ damage during cardiopulmonary bypass** 140
Andrew Snell and Barbora Parizkova
 12. **Cerebral morbidity in adult cardiac surgery** 153
David Cook
 13. **Acute kidney injury (AKI)** 167
Robert C. Albright
 14. **Extracorporeal membrane oxygenation** 176
Ashish A. Bartakke and Giles J. Peek
 15. **Cardiopulmonary bypass in non-cardiac procedures** 187
Sukumaran Nair
-
- Index* 199

Contributors

Robert C. Albright Jr DO

Assistant Professor of Medicine, Division of Nephrology and Hypertension, Mayo Clinic, Rochester, Minnesota, USA

Joe Arrowsmith MD FRCP FRCA

Consultant Cardiothoracic Anaesthetist, Papworth Hospital, Cambridge, UK

Constantine Athanasuleas MD

Division of Cardiothoracic Surgery, University of Alabama, Birmingham, Alabama, USA

Ashish A Bartakke MD (Anaesthesia), MBBS

ECMO Research Fellow, Glenfield Hospital, Leicester, UK

Gerald D. Buckberg MD

Distinguished Professor of Surgery, Department of Cardiothoracic Surgery, David Geffen School of Medicine at UCLA, Los Angeles, California, USA

Victoria Chilton BSc CCP

Senior Clinical Perfusion Scientist, Alder Hey Children's Hospital, Liverpool, UK

Simon Colah MSc FCP CCP

Senior Clinical Perfusion Scientist, Cambridge Perfusion Services, Cambridge, UK

Kevin Collins BSN CCP LP

Staff Perfusionist, Duke University Medical Center, Durham, North Carolina, USA

David Cook MD

Associate Professor, Department of Anesthesiology, Mayo Clinic, Rochester, Minnesota, USA

Kirsty Dempster CCP

Senior Clinical Perfusion Scientist, Cambridge Perfusion Services, Cambridge, UK

Helen Dunningham BSc CCP

Senior Clinical Perfusion Scientist, Cambridge Perfusion Services, Cambridge, UK

Liza Enriquez MD

Fellow, Department of Anesthesiology, Montefiore Medical Center, Albert Einstein College of Medicine, New York, USA

Betsy Evans MA MRCS

Registrar in Cardiothoracic Surgery, Papworth Hospital, Cambridge, UK

Steve Gray MBBS FRCA

Consultant Cardiothoracic Anaesthetist, Papworth Hospital, Cambridge, UK

Roger Hall MBChB FANZCA FRCA

Consultant Cardiothoracic Anaesthetist, Papworth Hospital, Cambridge, UK

George Hallward MBBS MRCP FRCA

Clinical Fellow in Cardiothoracic Anaesthesia, Papworth Hospital, Cambridge, UK

Charles W. Hogue MD

Associate Professor of Anesthesiology and Critical Care Medicine, The Johns Hopkins Medical Institutions and The Johns Hopkins Hospital, Baltimore, Maryland, USA

Brian Keogh MBBS FRCA

Consultant Anaesthetist, Royal Brompton & Harefield NHS Trust, UK

James Keogh MBChB FRCA

Clinical Fellow in Paediatric Cardiothoracic Anaesthesia, Royal Brompton & Harefield NHS Trust, UK

Andrew Klein MBBS FRCA

Consultant Cardiothoracic Anaesthetist, Papworth Hospital, Cambridge, UK

G. Burkhard Mackensen MD PhD FASE

Associate Professor, Department of Anesthesiology, Duke University Medical Center, Durham, North Carolina, USA

Sukumaran Nair MBBS FRCS

Consultant Cardiothoracic Surgeon, Papworth Hospital, Cambridge, UK

Barbora Parizkova MD

Clinical Fellow in Cardiothoracic Anaesthesia, Papworth Hospital, Cambridge, UK

Giles J Peek MD FRCS

Consultant in Cardiothoracic Surgery & ECMO, Glenfield Hospital, Leicester, UK

Susanna Price MBBS BSc MRCP EDICM PhD

Consultant Cardiologist and Intensivist, Royal Brompton & Harefield NHS Trust, UK

Linda Shore-Lesserson MD

Professor, Department of Anesthesiology, Montefiore Medical Center, Albert Einstein College of Medicine, New York, USA

Andrew Snell MBChB, FANZCA

Clinical Fellow in Cardiothoracic Anaesthesia, Papworth Hospital, Cambridge, UK

Steven Tsui MBBCh FRCS

Consultant in Cardiothoracic Surgery/Director of Transplant Services, Papworth Hospital, Cambridge, UK

John Wallwork MA MBBCh FRCS FRCP

Professor, Department of Cardiothoracic Surgery, Papworth Hospital, Cambridge, UK

Preface

This book has been written to provide an easily readable source of material for the everyday practice of clinical perfusion. For the past few years there has been a dearth of books, other than large reference tomes, relating to cardiopulmonary bypass. We hope that newcomers to the subject will find this book useful, both in the clinical setting and in preparation for examinations, and that more experienced perfusionists and medical staff will find it useful for preparing teaching material or for guidance.

We would like to thank everyone who helped in the preparation of the manuscript, particularly those who contributed their expertise by writing chapters for this book.

S. Ghosh, F. Falter and D. J. Cook

Equipment and monitoring

Victoria Chilton and Andrew Klein

The optimum conditions for cardiothoracic surgery have traditionally been regarded as a “still and bloodless” surgical field. Cardiopulmonary bypass (CPB) provides this by incorporating a pump to substitute for the function of the heart and a gas exchange device, the “oxygenator,” to act as an artificial lung. Cardiopulmonary bypass thus allows the patient’s heart and lungs to be temporarily devoid of circulation, and respiratory and cardiac activity suspended, so that intricate cardiac, vascular or thoracic surgery can be performed in a safe and controlled environment.

History

In its most basic form, the CPB machine and circuit comprises of plastic tubing, a reservoir, an oxygenator and a pump. Venous blood is drained by gravity into the reservoir via a cannula placed in the right atrium or a large vein, pumped through the oxygenator and returned into the patient’s arterial system via a cannula in the aorta or other large artery. Transit through the oxygenator reduces the partial pressure of carbon dioxide in the blood and raises oxygen content. A typical CPB circuit is shown in Figure 1.1.

Cardiac surgery has widely been regarded as one of the most important medical advances of the twentieth century. The concept of a CPB machine arose from the technique of “cross-circulation” in which the arterial and venous circulations of mother and child were connected by tubing in series. The mother’s heart and lungs maintained the circulatory and respiratory functions of both, whilst surgeons operated on the child’s heart (Dr Walton Lillehei, Minnesota, 1953, see Figure 1.2a). Modern CPB machines (see Figure 1.2b) have evolved to incorporate monitoring and safety features in their design.

John Gibbon (Philadelphia, 1953) is credited with developing the first mechanical CPB system, which he used when repairing an atrial secundum defect (ASD). Initially, the technology was complex and unreliable and was therefore slow to develop. The equipment used in a typical extracorporeal circuit has advanced rapidly since this time and although circuits vary considerably among surgeons and hospitals, the basic concepts are essentially common to all CPB circuits.

This chapter describes the standard equipment and monitoring components of the CPB machine and extracorporeal circuit as well as additional equipment such as the suckers used to scavenge blood from the operative field, cardioplegia delivery systems and hemofilters (see Tables 1.1 and 1.2).

Tubing

The tubing in the CPB circuit interconnects all of the main components of the circuit. A variety of materials may be used for the manufacture of the tubing; these include polyvinyl chloride